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1. Introduction

Studies of the development of energy demand - with the purpose of *projecting* the most likely development in the future or *prescribing* measures necessary to arrive at the most preferable future - often belong to one of two categories. On the one hand there are economic studies, that base the growth of energy demand on the growth of the economy and behavioral factors; on the other hand there are engineering studies, that are based on technological development and possibilities. Typically, these two types of studies produce seemingly contradictory results. The economic studies claim that, by definition, each reduction of energy demand below the "default" level is achieved at a certain *cost*. The engineering studies often show opportunities for significant energy savings at net *benefits* to society.

The purpose of this analysis is to shed some light on the transformation from the technical-economic potential for energy conservation within a sector, as calculated by engineering studies, and the actual growth of energy demand of this sector. In this way, some of the apparent contradictions between the two types of studies can be reconciled.

This study is based on an analysis of historical conservation potentials for some demand sectors and the subsequent development of energy demand in those sectors. The hypothesis is that the technical economic conservation potentials are of different predictive value for different sectors. This study aims at analyzing the transformation from the static energy-conservation potentials to the subsequent dynamic development of energy demand by comparing the three main sectors and several subsectors that have been studied. The three main sectors are space and water heating for buildings, electric appliances in homes and cars. The analysis is made for Sweden.

Many of the forecasts of the development of energy demand in Sweden predicted growth rates of energy demand that proved to be too high. In most cases they managed to follow the actual energy demand for only the first few years (Svensson and Mogren, 1984). In this study the development of *historically observed* energy demand, and not forecasts, is used for comparative analysis.

In Section 2 the methodology of the analysis made in this study is outlined and some definitions important in this context are defined. Section 3 contains an extended discussion about the dynamics of the energy-conservation potential. The actual analysis, including data and results, is described for the three main sectors in Sections 4 to 6 respectively. Finally, the results are summarized and some conclusions are drawn.

This study was done as part of the Young Scientists' Summer Program 1994 at the International Institute for Applied Systems Analysis in Laxenburg, Austria.

2. Methodology

2.1 Conservation Supply Curves

An energy conservation supply curve (CSC) is defined in Rosenfeld (1987) as a diagram in which the vertical axis shows the unit cost of energy conserved by various conservation measures and the horizontal axis shows the cumulative energy saved annually by that measure and all measures proceeding it (i.e., those with lower cost per unit of saved energy) on the supply curve. Given a CSC, the cost-efficient potential for energy conservation can be defined as the amount of energy that can be saved at a cost lower than that of fuel or electricity (the point on the horizontal axis where the supply curve crosses the energy price). An example of a CSC can be seen in Figure 2.1.

The CSC is a convenient way to illustrate the cost and energy conserved by different energy-conservation measures within a sector, as a total or with a certain time perspective.

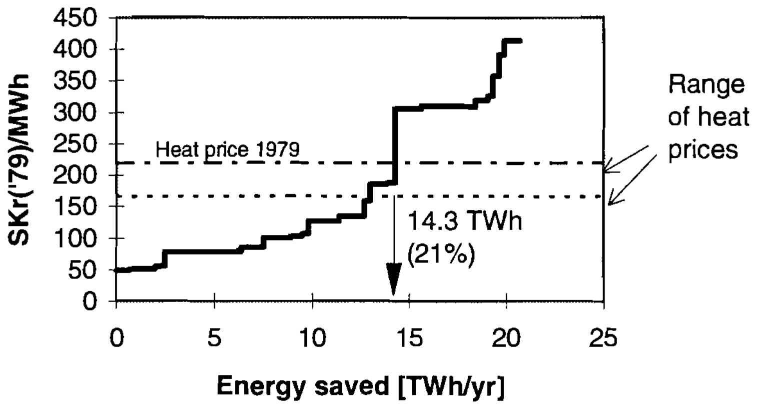

Figure 2.1 An energy conservation supply curve for residential buildings in Sweden in 1979. The upper and lower horizontal lines show the range of real heat prices [in 1979 Swedish Krona (SKr)] during the time period studied.

In this study a CSC is constructed for each sector studied to determine the cost-efficient potential for energy conservation. The sources of the different CSCs vary. For space and water heating the CSCs are based on extensive Swedish studies of conservation measures in the building shell. For electrical appliances and cars the data have been taken from studies originating in other countries (Denmark and the UK respectively) and are therefore only an approximation of the Swedish situation.

2.2 Energy Use and Conservation Potential

The goal of the analysis of historical energy demand is to study the transformation from an estimated savings potential to the subsequent development of actual energy use. One of the core questions is whether a categorization of demand sectors can be made, which is based on the level of importance of the technical conservation potential for the subsequent demand development.

For this analysis and for the comparison of the different sectors, at least three needs must be met: there must be a reliable estimate of the energy-conservation potential (in this study we have used 1979 as the reference year); sufficient statistical information about energy demand must be available; and there must be a well-defined point of comparison within the energy system.

For heat, the point of comparison should be at the level of useful energy demand (UED) (see Figure 2.3). The conservation measures considered for buildings decrease the demand for useful energy (or energy services). Hence, the CSC give the potential for conservation to further reduce the demand for useful energy and therefore, the analysis should be based on the development of *useful* energy demand. Accordingly, data on useful energy are used for the sectors for space and water heating in single family houses (SFHs), multifamily houses (MFHs) and commercial buildings.

For electrical appliances within households only data for final energy demand are available. For this sector some of the conservation measures considered conserve final energy, while others affect the demand for useful energy; therefore the point of comparison is less well-defined. This is a minor problem because fuel switching does not occur within the sector.

For cars the analysis is made for final energy and most of the conservation measures considered are applied at this level. However, passenger kilometers are also studied as a substitute for useful energy demand.

In all sectors considered, the estimate of conservation potential is based on estimates of the technological (not behavioral), cost efficient conservation measures in the technology or building stock of 1979. It is derived from different documented CSCs from 1979, in which a discount rate of 5% is used. The cost efficiency is determined using the real energy price for each year; however, the real price changes have, in general, been small (see Figures 2.1 and 3.1). To compare the different sectors, a measure of the cost efficient conservation potential in each sector is needed. For this purpose the potential in 1979, expressed in energy units and as a percentage of total energy demand of the sector in 1979, is used.

The cost-efficient potential used is, in several respects, a static potential, calculated for the stock and situation of 1979. In reality, the potential for efficiency improvements change dynamically over time due to several factors. The dynamic properties of the conservation potential are discussed further in Section 3.

The development of UEDs, gross domestic product (GDP), fuel prices, and other relevant factors is plotted relative to their 1979 values in the same diagram. These diagrams illustrate the differences in energy demand development between the various sectors. The development of fuel prices is of interest for two reasons: first, to determine the cost-efficient potential for savings, and second, to estimate the importance of changes in energy prices for the development of energy demand.

2.3 Measures of Improved Energy Efficiency

The difference between the actual development of useful (or in some cases final) energy demand and of hypothetical energy demand, [had demand developed at the same rate as gross domestic product related to a certain reference year (1979),] is calculated for the different years. In this study, the difference is defined as "*realized savings*"; it is expressed as a percentage of the estimated potential and is illustrated in the figures. One of the main purposes of ths study is the analysis of the differences in realized savings between the sectors.

The definition above relates an economic measure of energy efficiency to the technical energy-conservation potential. The economic measure of energy efficiency (relating energy use to economic activity) can include technological improvements as well as structural effects and changes in activity level. It can also be measured in terms of *demand decoupling*, a term often used in macroeconomic studies of energy demand. Demand decoupling factors (DDFs) are defined and further discussed in the next section.

The definition of realized savings or energy efficiency improvements is in no way self-evident. In more technologically detailed studies, other definitions of energy efficiency improvements are used. One example is "the difference between actual energy use and the amount of energy that would have been used in a given year if energy intensities in each sector were frozen at a base year level, but the activity and structure of each sector had evolved as it actually did" (Schipper et al., 1993). This definition is related to how efficiently a certain level of "energy services" can be accomplished.

2.4 Demand Decoupling Factors

In energy economy models, energy is introduced as one of the economy´s production factors. In most realistic cases this leads to a strong relation between energy demand and the general growth of the economy. Changes in relative energy prices (if energy prices increase more or less than prices for other goods) will differentiate the growth of energy demand from that of the GDP, following some estimates of price elasticities. In addition, there will be effects that are not caused directly by changes in energy prices. Examples are technological development and structural change that affect energy use but are driven by forces other than the price of energy (Figure 2.2). In economic models of the energy system these different factors affecting the growth rate of energy demand are often summarized in a correcting factor called autonomous energy efficiency improvement (AEEI; the word "autonomous" here means *not* price induced) or DDF.

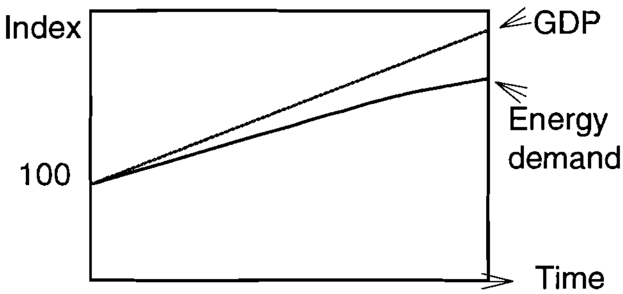

Figure 2.2 The gap between the growth of GDP and the growth of energy demand. This gap is usually modeled with the AEEI or DDF in energy economic models.

This correcting factor includes many phenomena other than strictly energy efficiency improvements. Also, *reduction* in energy efficiency as well as structural change (for example, industry changing from materials to services and modal shifts in transportation) can be hidden in the factor. As a whole, it is a correction factor to account for the resulting decoupling of energy demand from economic growth. Therefore the alternative term DDF has been established within ETSAP[1] and will be used in this paper.

A DDF can be determined for the aggregate energy demand, for different energy demand sectors, and in relation to different energy accounting points in the energy system, i.e. for primary energy, final energy, or useful energy. If it is determined in relation to final or primary energy, it also includes effects of fuel switching or efficiency improvements in the supply of energy. The DDF can be either positive, meaning that energy demand grows slower than GDP, or negative, meaning that it grows faster than GDP.

[1] Energy Technology Systems Analysis Programme, International Energy Agency. The demand decoupling factors are used with the MARKAL-MACRO model (Manne and Wene 1992).

In Sections 4 to 6 the directly observable decoupling between energy demand and economic growth is calculated as the difference between the growth rate of GDP and the growth rate of energy demand (for useful or final energy). This difference is here termed *compounded* DDF (CDDF). If the economy grows by 3% a year and the energy demand of a specific sector grows by 2%a year the CDDF for this sector is 1% a year.

The development of energy demand for this same sector can be divided into two parts, one part being dependent on changing energy price and the other part being autonomous (i.e. *not* caused by change in energy price for this sector). If the real energy price increases with 2% a year during the same period, it can be assumed that the slower growth of energy demand depends on this price increase (with a price elasticity of 0.5, the demand decreases 1% for every 2% price increase) and that there is no autonomous decoupling. On the other hand, if the real energy price has decreased the autonomous decoupling would be even higher.

Accordingly, CDDF is a combination of the *price-induced* DDF (PDDF) and the *autonomous* DDF (ADDF), where the ADDF directly corresponds to the term AEEI above.

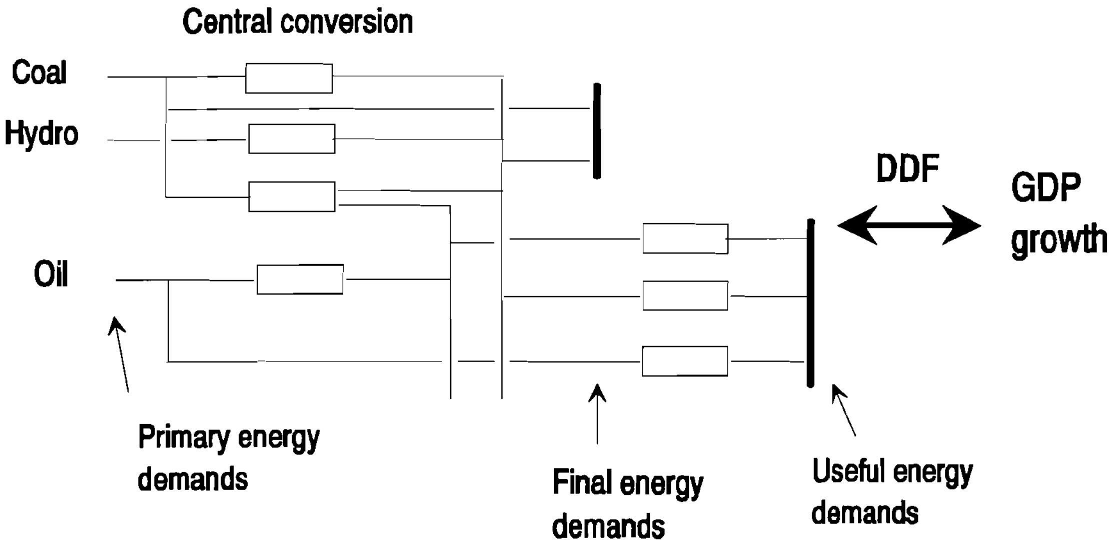

Figure 2.3 Reference energy system illustrating different energy accounting points and their relation to DDF and economic growth.

Figure 2.3 illustrates a simplified energy system, indicating the various energy accounting levels. The DDFs are factors "between" economic growth and energy demand. For some demand sectors (electrical appliances or industry) only statistics for final energy demand are available; the DDF then include efficiency changes in the conversion to UED. For other sectors (heating), UED can be calculated and the DDF represents a smaller "gap" in the figure. For national aggregated energy use it might only be possible to calculate the DDF related to primary energy demand. It then "includes" most of the energy system. For all these levels we can distinguish between CDDFs, PDDFs, and ADDFs.

The CDDFs are directly related to the realized savings calculated in Sections 4, 5, and 6. The realized savings in energy units are calculated as the difference between actual energy demand and the hypothetical energy demand (had it developed at the same rate as the GDP). The CDDFs are defined as the differences in *growth rates* between the same factors (actual energy demand and GDP).

The CDDFs are thus related to the technical potential for energy efficiency improvements in the same way as are realized savings. The strength of this relation differs between the various sectors (see Figures 4.2, 4.4, 5.3, and 6.3). A high CDDF does not necessarily imply that the sector has realized the technical potential for energy savings to a great extent. The *relative* realization also depends on the size of the technical potential for the sector in question. This latter factor is not included in the CDDFs.

3. Dynamics of Potentials

3.1 Background

A CSC illustrates the situation at a certain point in time. The curves used in the main analysis above relate to the stock of buildings or technology in 1979 and illustrate the extent to which this stock can be made more energy efficient. The potential for cost-efficient energy savings is derived from this curve comparing the cost of efficiency improvements with the price for energy. The estimated potential, even if calculated for different years, always relates to the technology stock of 1979. However, the development of energy demand and the realized savings, take place in the *total* dynamically developing stock.

Naturally, the conservation potential also changes dynamically. Over time the CSC changes due to changes in several parameters: the information about the various conservation measures improves, new technologies are developed, and the costs for different energy-conservation measures change, as does the stock available for the various measures.

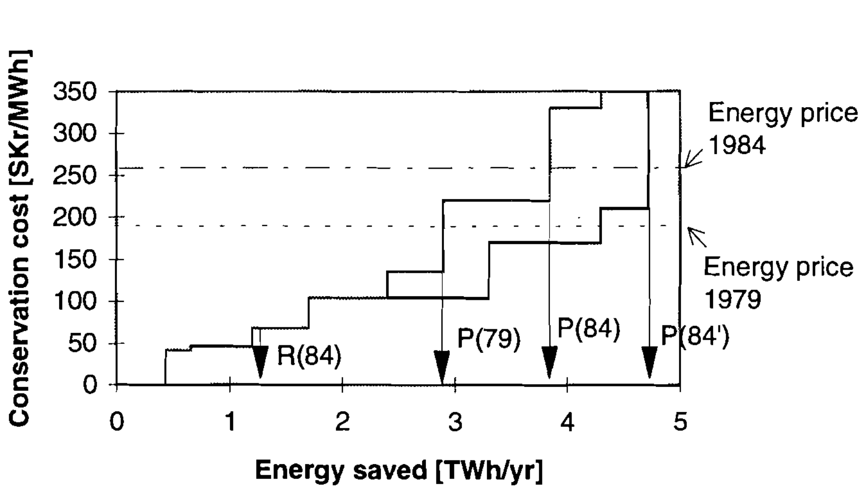

Figure 3.1 Dynamic changes of the energy CSC and, thereby, of the cost-efficient energy conservation potential. P(79) is the cost-efficient conservation potential in 1979. P(84) and P(84') are the alternative measures of the cost-efficient potential in 1984, when the energy price and CSC have changed. R(84) is the energy savings accomplished between 1979 and 1984.

An attempt to illustrate the development of the CSC over time can be found in Figure 3.1. As some of the potential is realized, the costs and energy that can be saved by not-yet-realized measures change, and the price of energy changes. Which potential should be used to calculate the percentage of realized savings?

The effects of the dynamics of the conservation potentials are complex and cannot be fully explored in this paper. In the main analysis presented above, the changing heat prices were acknowledged. For each year the cost-efficient potential for energy conservation was determined with the real heat prices for the actual year. The change in cost-efficient potential due to these price changes was small (see Figures 2.1 and 5.1). From a technical point of view, these are the prices that determine which energy conservation measures would be cost-effective to pursue for this specific year, provided that the energy prices stay at least as high during the technology's pay back period.

In this section an attempt is made to consider the effect of improved information on the cost and performance of conservation measures in order to estimate how important the dynamic effects are for the analysis.

3.2 Dynamics of Conservation Supply Curves

Change in conservation potential over time

Apart from the CSCs for 1979 used in the main analysis, there are CSCs available for the building sector in 1990. From both these curves the cost-efficient conservation potential can be estimated. The difference between the two potentials depends on the change in the capital stock of the sector (in this case buildings), conservation already achieved, and technological development (improving the energy-conservation possibilities).

The building sector is comparatively static, meaning that the building stock changes slowly. As different conservation measures are taken and as new buildings are constructed to be more efficient, the potential for further efficiency improvements decreases. For other sectors (such as electrical appliances) this might not be the case, because new end uses are incorporated into the sector.

For the building sector the decrease in estimated potential can be compared with the realized savings. The realized savings, as calculated in this study, depend on several factors, such as technical energy efficiency improvements, and structural and behavioral change. The comparison can provide some information about how much of the realized savings depends on the CSCs, i.e., on technical measures to improve energy efficiency, and how much depends on other factors, such as changes in behavior. For the heat used in buildings this part would be expected to be comparatively large because of the static nature of the building sector. The decrease in estimated potential should be similar to the realized savings.

For the residential sector as a whole, the decrease of the potentials from 1979 to 1990 (4.9 TWh/yr) are, in fact, found to be very similar to the size of the realized savings in 1990 (5.7 TWh/yr). For commercial buildings the corresponding numbers are 4.2 TWh/yr and 3.2 TWh/yr. These results indicate that for the space and water heating sector the dynamic effects are small. The distribution of the effect between the subsectors SFHs and MFHs, confuses the picture (see also Section 4.4). The realized savings are much larger than the decrease in potential for MFHs; conversely, for SFHs they are much smaller.

For the residential sectors the CSCs for 1990 are based on a thorough revision of those from 1979. This revision, made in 1985, led to changes in costs of energy and energy saved through the various measures and to the addition of a few conservation measures. For commercial buildings the information in 1979 was more or less transferred from MFHs. In 1990, a new study specifically of commercial buildings was available (Claesson and Enevold, 1994), on which the new conservation potential is based. This study included a small number of measures, because only those that were very cost-efficient were presented. This naturally affects the comparison presented above.

Change of conservation potential due to research and development

Alternative CSCs for 1979 can be constructed using the information available in 1985. This has been done for only part of the building sector, namely, residential buildings (Figure 3.2). The alternative curves illustrate the energy-conservation potential in 1979 for the building stock of 1979, but with the *knowledge* about costs and energy savings possible that was available in 1985. The difference between these curves and the original curves for 1979 could serve as an indicator of the technological development (including information enhancement) during the eighties. Since the revision of 1985, the interest in improving available measures and information for this demand sector has declined. The other two factors affecting the change in potential, namely, the change in building stock and the conservation measures already taken, have been eliminated by using the same reference year.

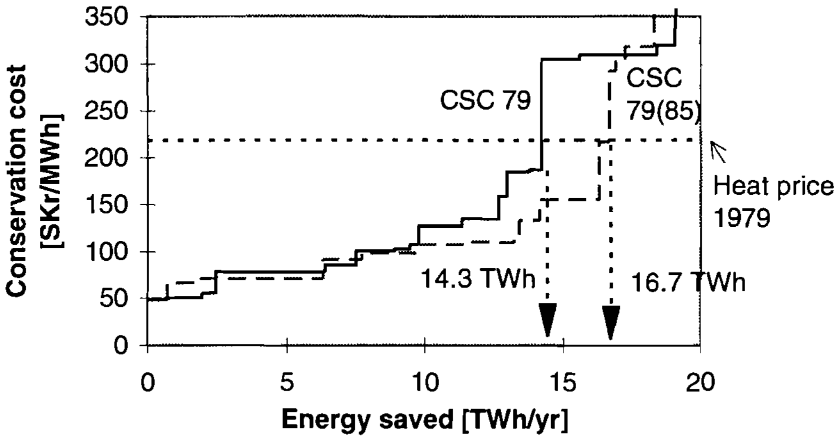

Figure 3.2 Two different CSCs for residential buildings in 1979, with the knowledge of 1979 (CSC 79) and 1985 (CSC 79(85)), respectively.

As expected, a comparison of the two curves (using the same energy prices) shows that the potential for energy conservation increases with increased knowledge. The difference is about 2 TWh/yr, or 15% of the potential used in the main analysis. As before, the results for the two subsectors, SFHs and MFHs, are less clear. This is discussed further in Section 4.4.

If the original 1979 CSC is used to determine the potential for energy conservation in 1979 and 1984 and the alternative curve is used to determine the potential in 1987 and 1990, a revised diagram of the realized savings can be constructed. This diagram will, to some extent, take the dynamic changes of the energy-conservation potential into account. The result is shown in Figure 3.3. One can see that the peak in realized savings of 1987 is less marked when the dynamic changes in potential are introduced; however, the overall picture remains the same.

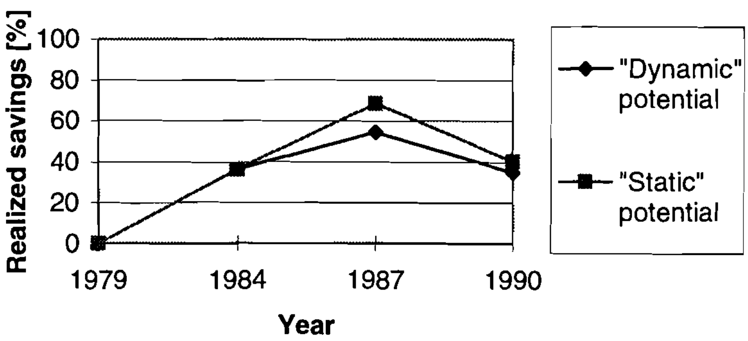

Figure 3.3 Realized savings (as a percentage of estimated potential) when a changing conservation supply curve is used. For comparison, the curve showing the case with one "static" conservation potential is also shown.

4. Space and Water Heating in Buildings

For the analysis of space and water heating, the information about conservation potential is taken from work done in the late seventies by Wene and Andersson (1983). This work is documented and updated through the computer model HOVA, which calculates energy demand and energy-conservation potential from data on building stock and conservation measures.

The data on final energy demand (FED) are taken from a recent analysis of energy use in Sweden (Schipper et al., 1993) and directly from Swedish statistical sources. These data are converted to UED, using documented conversion factors from earlier studies of the Swedish energy system (Wene, 1980; Vattenfall, 1992).

Other information needed is readily available from official sources of statistics (SCB, 1982/83, 1986 and 1992) and in Schipper et al. (1993).

4.1 Residential Buildings (Total)

Conservation supply curves

A CSC for 1979 has been reproduced for the sesidential space and water heating sector (see Figure 2.1). It considers the building stock in 1979 and conservation measures that were at that time expected to conserve energy within the sector. The estimates of costs, energy conservation, and part of the building stock available for each measure are from 1979. The CSC is constructed with the help of the HOVA program.

The costs for the various conservation measures are expressed in Swedish krona (SKr) at 1980 value, and the discount rate used is 5%.

An alternative CSC for 1979 can be constructed for the same building stock, but with the *knowledge* about conservation technologies and reconstruction costs that existed in 1985. This revised CSC is used and discussed further in Section 3.3.

The building stock for the year studied is needed as input to the HOVA program. In HOVA the building stock is divided into different age classes, with different data on conservation measures and energy use. Information about the building stock is taken from the publications of the National Central Bureau of Statistics from as near the year

1979 as possible. The assumptions made and the derived building stock are presented in Appendix A.

Useful energy demand

The development of FED for the total residential space and water heating sector is taken from Schipper et al. (1993). In the calculation from FED to UED the conversion efficiencies are assumed to improve over time. The estimates of efficiency values are taken from the Swedish Markal databases for 1990 and for 1980. The in-between values are interpolated. In the corresponding calculations in Schipper et al. (1993), *constant* conversion efficiencies for each energy carrier are used. Use of these values produces higher estimates of realized efficiency improvements, because energy efficiency improvements in the heating equipment (furnaces) are included.

The statistical data on FED fit well between different sources (Schipper et al. 1993; L-G Carlsson 1992; and SCB 1993). However there are some discrepancies regarding the division of electricity use between space and water heating versus other end uses. For the estimates of UED there are larger differencies, due to different bases for climate correction and different assumptions about conversion efficiencies. The UED in HOVA for 1991 (Claesson and Enevold, 1994) is comparatively low. This demand is calculated based on building statistics and not taken directly from energy demand statistics. The data from Schipper et al. (1993) are used for all years considered to achieve a consistent treatment of the statistical material.

The CSC in Figure 2.1 relates to the building stock existing in 1979; the development of UED is taken for the complete building stock evolving over time.

Other factors

The development of GDP is an essential part of this study. It is the basis for the comparison of energy demand growth between different sectors and for the calculations of realized savings in different sectors. Also, the development of population is of interest for the residential sector, because the number and size of dwellings are closely connected with the size of population. These data are available in official statistics, but are taken here from Schipper et al. (1993). The data on population development illustrate the fact that only a small part of the GDP growth during this time period is caused by growth in population. Data on population are not used in any calculations.

Heat prices

In Table 4.1, prices for *heat* (as useful energy) from electricity (El.), oil, and district heating (DH) are weighted together to yield *one* heat price for each of the four years studied. The price ranges for different heat sources are also displayed. The information is deduced from several different sources (Värmeverksföreningen 1983-1990; SPK 1987 and 1990; and Carlsson 1992), for several different years. When possible, the data from official sources of statistics have been used.

The current heat prices have been corrected with the consumer price index (CPI) to yield the real price development. All the values in the table are the total heat prices to the customer, including taxes and VAT. It is this total price that the consumers face, and react to, when deciding whether to invest in an energy efficiency measure. Fuel wood prices have not been included in the calculation of this price-development.

Year	1979	1984	1987	1990
Heat price, current SKr/MWh Average High Low	 193 195 (El./DH) 190 (Oil)	 317 400 (Oil) 254 (El.)	 280 350 (El.) 225 (Oil)	 403 500 (El.) 325 (DH)
Consumer Price Index	88.0	143.2	167.0	207.6
Heat price, real SKr/MWh ('80)	219	221	167	194
Heat price index	100.0	100.9	76.3	88.6

Table 4.1 Weighted average heat prices from 1979 to 1990.

4.2 Separation into Single-family Houses and Multifamily Houses

Conservation supply curves

All information and calculations in HOVA are made for the two subsectors, SFHs and MFHs. Therefore, CSCs can easily be constructed and energy-conservation potentials can be derived for these two subsectors. The CSC described above is simply the sum of these separate curves.

Useful energy demand

Determining UED for SFHs and for MFHs is also fairly straightforward. The data on energy demand in Schipper et al. (1993) are only for the total residential sector, and cannot be used directly; however, statistics are available for SFHs and MFHs separately (SCB 1989 and 1993). There are some difficulties in the division of use of electricity into heat and appliances, respectively; however, this division is also estimated in the statistical sources.

For the calculation of UED, the SCB data (SCB 1989 and 1993) for FED have been used directly. The conversion efficiencies between final and useful energy differ depending on the subsector; larger furnaces in MFHs are more efficient than are small ones in SFHs. The energy used for space heating is climate corrected using the ratio of the actual number of heat degree days to the normal number of heat degree days. Of the total energy used for space and water heating, 75% is assumed to be used for space heating. This method of correcting for changing weather conditions is consistent with the method used in Schipper et al. (1993). For 1990, a distinction is made in the statistics between heat produced within a specific subsector (MFH or SFH) and heat used by the same subsector. The demand values used are from the subsector using the energy, but the conversion efficiencies are from the producing subsector.

A comparison of the sum of the energy demand from SFH and MFH (calculated as described above) and the total residential energy demand in Schipper et al. (1993) showed the values to be consistent.

Heat prices

To perform the analysis for the two subsectors, the heat prices must be specified for each sector (Table 4.2). The differences between the heat prices for SFHs and MFHs are not negligible. However, only one of the sources for price information makes this distinction (Carlsson, 1992). The data from this source have been adapted in order to be consistent with the overall price development in Table 4.1.

Year	**1979**	**1984**	**1987**	**1990**
SFH (SKr/MWh)	210	330	310	450
Heat price index	100.0	98.8	79.6	92.9
Heat price, real SKr/MWh ('80)	233	230	185	216
MFH (SEK/MWh)	170	280	270	370
Heat price index	100.0	103.5	85.6	94.4
Heat price, real SKr/MWh ('80)	189	196	162	178

Table 4.2 Adapted heat prices (in Swedish krona) for single-family houses and for multifamily houses for the years used in this study.

4.3 Commercial Buildings

Conservation supply curves

The energy CSC for commercial buildings can also be constructed using the HOVA program. The same type of input data as as used for the other sectors are needed. The data on the building stock can be found in Appendix A.

The data on energy-efficient technologies used to derive the CSC for commercial buildings are almost identical to the data for MFHs; there are a few cost differences and a few additional technologies related to the work on energy efficiency improvements in buildings from the late seventies (Wene and Andersson, 1983).

Useful energy demand

The data on useful energy for commercial buildings are available from the same sources of statistics as used for SFHs and MFHs. In these sources no data for 1979 are available; data are available only for 1978. The total statistics for the commercial sector for the years from 1970 to 1990 are available in a report by Schipper et al. (1993). In these numbers the electricity is not separated into electricity used for heating versus electricity for other end uses. The climate-corrected UED is calculated from both these sources. In both cases the values for electricity are taken from the SCB statistics (1989 and 1993). The data series derived from the two sources are not wholly consistent (see Table 4.3).

The data from Schipper et al. (1993), have been used in the main analysis of Section 4.4. The corresponding curves using the SCB statistics (SCN 1989; and SCB 1993), can be found in Appendix B.

Useful energy demand (Twh)	**1979 (1978)**	**1984**	**1987**	**1990**
SCB, 1989 & 1993	26.59 (24.83)	22.36	22.58	28.21
Schipper et al., 1993	26.92 (25.14)	25.41	25.62	29.64

Table 4.3 Useful energy demand for heat in commercial buildings, derived from two different sources.

Heat prices

For commercial buildings the same heat prices as used for MFHs are valid.

4.4 Analysis and Results

General

The residential building sector is especially well suited to this type of analysis, due to its comparatively static nature. This means that the conservation potential for space heat in the residential sector is comparatively static, as well. Also, the demand sector for space and water heating is well defined, and the statistics allow us to perform the study in terms of useful energy. Finally, the CSCs are based on extensive Swedish studies of residential buildings from this time and are considered to be reliable.

Commercial buildings share several of these characteristics, but there are also differences. The heat used in commercial buildings can be for heating of swimming pools, warehouses, offices, or hospitals, and thus the end use is not as well defined. Also, the commercial sector is more sensitive to different phases of the business cycle. Finally, the CSCs used here are less reliable for commercial buildings than for residential buildings, because the data are mostly transferred from MFHs.

Residential sector

To summarize the results for the residential sector as a whole, the growth of UED is somewhat smaller than the growth of the GDP (Figure 4.1). The realized savings were shown to add up to a maximum of about 60% in 1987; however, they declined to 40% in 1990. In the beginning of the 1980s the Swedish authorities introduced a massive weatherizing program for residential buildings. From the realized savings listed above, one can conclude that this program achieved about half of the potential for conservation.

An increase in the energy demand growth (and a decrease in realized savings) during the last years studied (1987 to 1990) can be observed for the entire sector. This increase is assumed to be related to the drop in fuel prices from 1986 and the subsequent decreased general interest in energy savings.

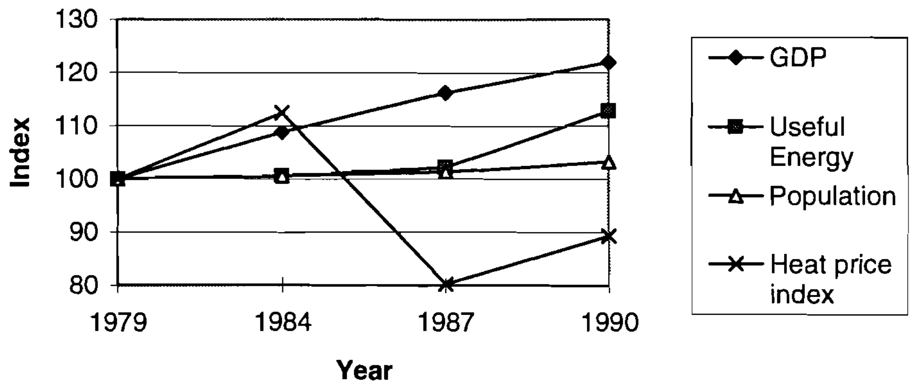

Figure 4.1 Relative development of UED, GDP, population, and heat prices for all residential buildings (including both SFHs and MFHs) in Sweden.

When separating the residential sector into the two subsectors, SFHs and MFHs, more intriguing patterns were achieved. The two subsectors looked remarkably different.

For SFHs the UED followed GDP closely and the overall realized conservation potential was small, despite a distinct peak in 1987.

For MFHs a maximum of almost 150% of the conservation potential was realized (1990). The realized savings continued to increase for the entire time period, and the "usual" decrease after 1987 was *not* observed (Figure 4.2). The UED decreased somewhat during the first five years and thereafter increased slowly until 1987. The overall growth rate was even lower than the population growth rate.

Realized savings over 100% are not in any way illogical, they simply mean that the realized savings (defined according to Section 2.2) were larger than the 1979 estimate of the cost-efficient conservation potential. This can be the result of e.g. a change in demand structure or a misjudgment of costs and energy savings from energy efficiency measures. In this case, the very high realized savings in 1990 (and the correspondingly low value for SFHs), might be caused in part by an update of the definitions of the sectors used in the sources of statistics.

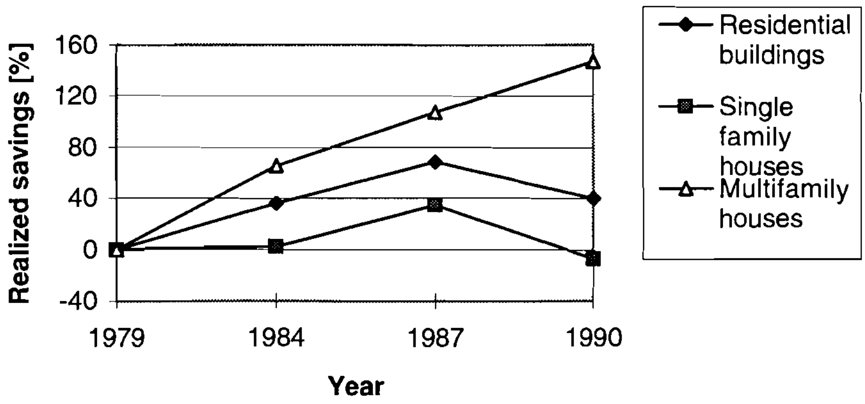

Figure 4.2 Realized savings in percentage of estimated potential for cos-efficient conservation, for the sector of residential buildings and the two subsectors. At 0% the actual energy demand and the hypothetical energy demand (had it grown at the same rate as GDP since 1979) coincide; at 100% the difference between these two measures is equal to the estimated savings potential.

The reasons for the difference between SFHs and MFHs are as yet uncertain, but there are a number of plausible explanations. First, it can be an indication of success of the government's weatherizing program, because the subsidies in this program have largely been directed toward MFHs. Second, there has been some structural change in the residential sector. According to Schipper et al. (1993) the number of MFH dwellings remained constant between 1979 and 1990, meaning that all of the growth in the total number of dwellings (about 7%) occurred in SFHs. Because we are looking at marginal changes of the energy demand this type of minor shift could affect the result. Finally, an observation can be made that the costs for energy-conservation measures have in general been estimated to be somewhat lower for MFHs than for SFHs (although in both cases they are cost-efficient). Thus, the use of a higher discount rate would result in a higher potential in MFHs than in SFHs.

The differences between the two subsectors are especially noteworthy: differences in ownership are expected to favor conservation measures in SFHs, because SFHs are mostly occupied by the owner and MFHs are mostly occupied by renters.

Commercial sector

For commercial buildings the development of UED is less stable than for residential buildings (Figure 4.3) . This energy demand decreases significantly for the first five years, remains almost constant for the next three years, and increases significantly for the last three years. This pattern indicates a strong, somewhat lagged, reaction to changing heat prices. The increase in the last years of the time period studied is analogous to the pattern of the residential buildings, where the demand for heat is almost constant until 1987 and thereafter increases considerably.

The total floor area in the commercial sector was introduced as a factor to see whether differences between growth of the economy and the energy demand depended on shifts in the structure of the economy. Interestingly, the total floor area of the sector grows steadily at almost exactly the same growth rate as the GDP, despite the large shifts in energy demand.

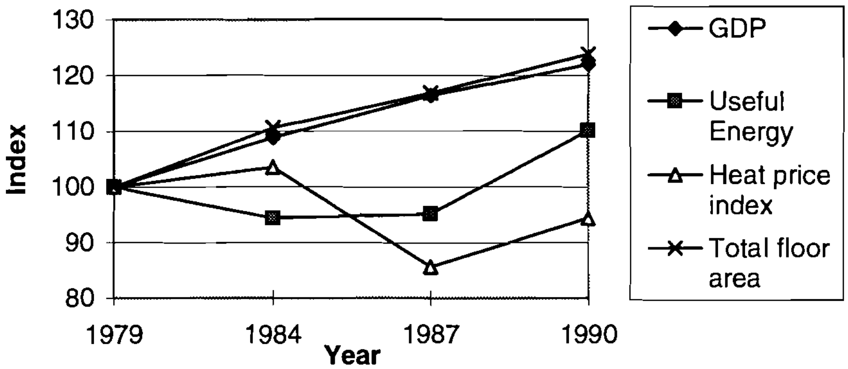

Figure 4.3 Relative development of UED, GDP, floor area, and heat prices for commercial buildings in Sweden (Schipper et al., 1993).

The realized conservation as a percentage of the estimated potential is very high; it reaches 92% in 1987 and declines to 52% in 1990 (Figure 4.4). If the data from Statistics Sweden (SCB) in Table 4.3 were used, the realized potential would be considerably higher (see Appendix B).

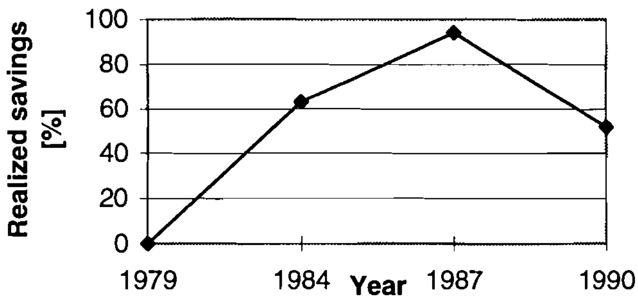

Figure 4.4 Realized savings as a percentage of the estimated potential for commercial buildings in Sweden.

Demand decoupling factors

Approximate historical values for the CDDFs can easily be derived by taking the difference between the growth rates of the actual energy demand and the growth rate of the economy. The derived numbers thus include price-induced demand changes (no correction has been made for the effect on energy demand by the change in relative energy prices).

CDDF (%/year)	Average	1979-1984	1984-1987	1987-1990
Residential heat				
Total useful energy	0.72	1.6	1.7	-1.8
Total final energy	2.05	3.3	3.5	-1.6
Single family, UED	-0.04	0.3	2.3	-2.8
Multifamily, UED	2.69	2.8	1.6	3.6
Heat, commercial buildings,				
Total UED	0.94	2.9	2.0	-3.4

Table 4.4 Approximate values of the CDDFs for the building sectors between 1979 and 1990.

Table 4.4 illustrates the importance of the energy accounting point used. For the whole residential sector the CDDF in relation to UED is 0.72%/yr, close to the values often used (Manne and Richels, 1992) for *final* energy demand. For final energy demand, on the other hand, the CDDF is much higher, due to a high degree of electrification of the residential heat sector in Sweden during this time period. The losses are thus moved to the supply side. These losses would be incorporated in the CDDF for *primary* energy (had it been calculated), which would then be considerably lower than for final energy. These effects are often significant and should be properly recognized, because the energy system is represented differently in different models, which leads to very different DDF values.

The effects on CDDF of the level and method of disaggregation into various sectors are apparent. The division of the total residential sector (CDDF = 0.72%/yr) into SFHs and MFHs gives completely different values (CDDF = -0.04%/yr and CDDF = 2.69%/yr, respectively). The price development has been very similar for the two subsectors, which indicate that the result would be similar had the autonomous DDFs been calculated.

5. Electrical Appliances for the Residential Sector

In this study the potential for energy conservation in household electrical appliances is based on data from a Danish study by Nörgard (1979).

The development of energy demand, both for all electricity used for purposes other than heating in the households, and for the various specific end uses (cooking, lighting, etc.) are taken from Schipper et al.(1993). For this sector final, and not useful, energy demand is used.

5.1 Electrical Appliances (Total)

Conservation supply curves

To construct CSCs for residential appliances, data have been taken from Nörgard (1979), regarding the Danish energy system. Nörgard estimates the possible savings of energy used for cooking, refrigerating, washing, dishwashing, etc., for moderate, strong, and radical measures. In this work the "strong measures" have been used to estimate the potential for savings. The measures are of a purely technological nature and no behavioral aspects are taken into account.

The analysis in Nörgard (1979) was made for Denmark in 1975. In this study the reference year 1979 is used; therefore, some assumptions were made to convert the data for Denmark in 1975 to Sweden in 1979.

In Nörgard (1979) there is information about "normal" unit consumption for each end use in kWh/yr (1975 average), unit consumption (kWh/yr) *after* the measures are taken and the cost for each conservation measure. The savings potential per end-use unit is the difference between normal unit consumption and unit consumption after the conservation measures. In Nörgard the energy saved through the various measures is calculated for Denmark, i.e. the technology used in Denmark and the Danish usage pattern in 1975 determine the "normal" unit consumption. For determining the unit consumption after conservation measures are taken, the same usage pattern as in 1975 is assumed.

The Swedish data (Schipper et al., 1993) on average unit consumption in 1975 and 1979 (before measures are taken) for the various appliances do not coincide with the Danish data for the same years. There are two different methods that can be used to calculate the energy saved through the various measures for the Swedish case:

1) Calculate the *difference* between "normal" Swedish unit consumption and the unit consumption after a certain conservation measure. This would be the case if the reason for the difference in "normal" unit consumption between Sweden and Denmark is that Swedes and Danes used different technology at the beginning of the period, but the final level after technological development was the same.
2) Use the same reduction of energy use *in percentage* for the Swedish appliances as is calculated for the Danish appliances. This could be the case if behavioral aspects were the reason for the difference in "normal" level; for example, if Swedes have more lamps in the house, or use larger freezers. Because no change in behavior is assumed, the technological change would be proportional to the starting values.

In both these methods, because one of the two variables (technology used or usage pattern) is kept constant, the different starting years (1975 and 1979) do not affect the analysis. In reality both factors change over the years and between the countries.

In this study two estimates of the savings from each measure have been calculated, using the two methods described above. From these data, two different CSCs for the total appliance sector have been constructed, one giving a high and the other a low conservation potential. The total savings possible from each measure are calculated by multiplying the total number of appliances in Sweden in 1979 by the energy savings per measure. For the "high" CSC the highest savings estimate for each appliance has been used; for the "low" CSC, the lowest has been used. Both curves will thus be the result of a mixture of the two methods. All the data used for these two CSCs can be found in Appendix C.

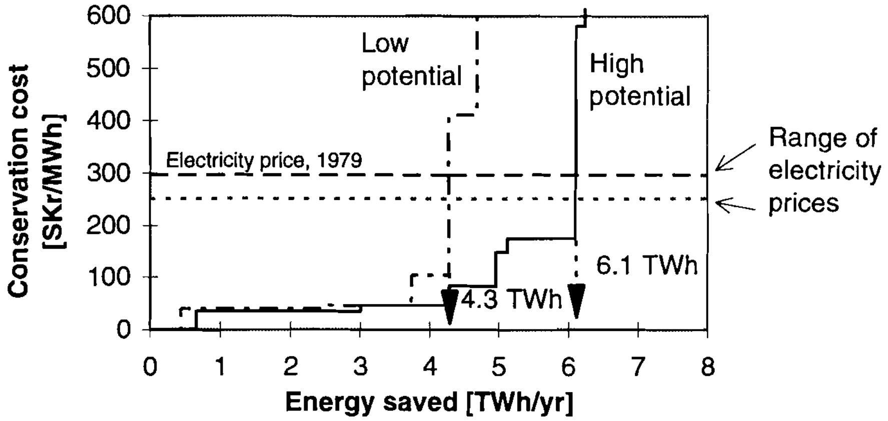

Figure 5.1 Conservation supply curves for electric appliances in homes; "high" versus "low" case. The high potential is 6.1 TWh/yr or 49% of the sector's final energy demand, and the low estimate adds up to 4.3 TWh/yr or 35% of demand. The upper and lower horizontal lines show the range in real electricity price during the time period studied.

Only the conservation measures for large appliances are included in Figure 5.1, because no information about unit energy use or market penetration levels are available for small appliances. Large appliances here refer to electric stoves and ovens, refrigerators, freezers, washing machines, clothes dryers, dishwashers, and lighting. Other appliances, not named, considered to be small appliances.

Cost of efficiency measures

The cost per MWh saved is calculated for each conservation measure. In Nörgard (1979) the incremental costs for each conservation measure are available in 1975 US dollars. These numbers are annualized with a discount rate of 5% and with an assumed lifetime of 10 years (five years for lighting). To enable comparison of these numbers with heat prices, the costs are converted to 1980 Swedish krona (SKr).

Final energy demand

For this sector the *final*, and not useful, energy demand has been used, because it is the only information available. This is a minor problem for electrical appliances because there is no fuel shifting within the sector. Final energy use in the whole sector as well as for each of the large appliances (unit energy use per year and market penetration levels) are available in Schipper et al. (1993). The development of energy demand in this sector is presented partly as total energy used, and partly as energy used for the large appliances defined above. The energy demand for small appliances equals the difference between these two measures, but is not presented explicitly because there is no estimate available on the savings potential for these appliances.

Electricity prices

The price of electricity for residential customers in Sweden depends on whether the customer has electric heating. In this study the higher price (without electric heating) is used. The price series is shown in the Table 5.1 (Carlsson, 1992).

	1979	1984	1987	1990
Electricity price (SKr/MWh)	260	360	420	585
Electricity price, real ('80 SKr/MWh)	296	251	252	282

Table 5.1 Electricity prices for residential customers without electric heating.

5.2 Electrical Appliances Disaggregated

For each of the end uses within the large appliances category two different conservation potentials can be calculated, according to methods one and two described in Sector 5.1. Note that for some appliances method one will give a higher estimate of the potential, and that for others method two will show larger opportunities to save energy. Not all of these are costefficient, however. For dishwashers and cooking, only the high potential is costefficient and for clothes dryers neither potential is cost-efficient.

The development of FED for each end use can be derived from a combination of information (Schipper et al., 1993) about unit electricity consumption per year for each appliance and data on market penetration levels (percentage of households in Sweden owning the various appliances) and total number of dwellings for the different years.

5.3 Analysis and Results

Electrical appliances (total)

The high estimate of the savings potential for the whole sector is 49% (6.1 TWh/yr) of the total FED for electric appliances in households in 1979. The low estimate is 35% (4.3 TWh/yr).

Total final energy use for electrical appliances in the households increases slightly faster than does the GDP (Figure 5.2). The final energy use for large appliances (as an aggregate) decreases considerably, indicating that the energy demand supplying other, new types of appliances increases markedly.

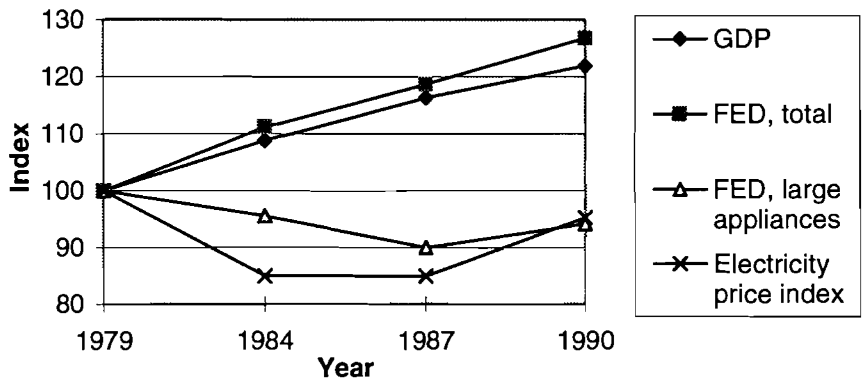

Figure 5.2 Relative development of FED, GDP and electricity price for electrical appliances in homes in Sweden. Final energy demand for all electric appliances and for only large appliances only are both plotted.

The realized savings for the whole sector are thus negative, again showing that the engineering savings potential used in this analysis (Nörgård, 1979) does not capture the dynamic changes of energy demand (i.e. introduction of new types of appliances) (Figure 5.3). For large appliances (the types of appliances actually studied by Nörgård) the savings reach 50% of the high potential and 70% of the low potential. The increase continues during the whole time period studied, but slows down markedly after 1987.

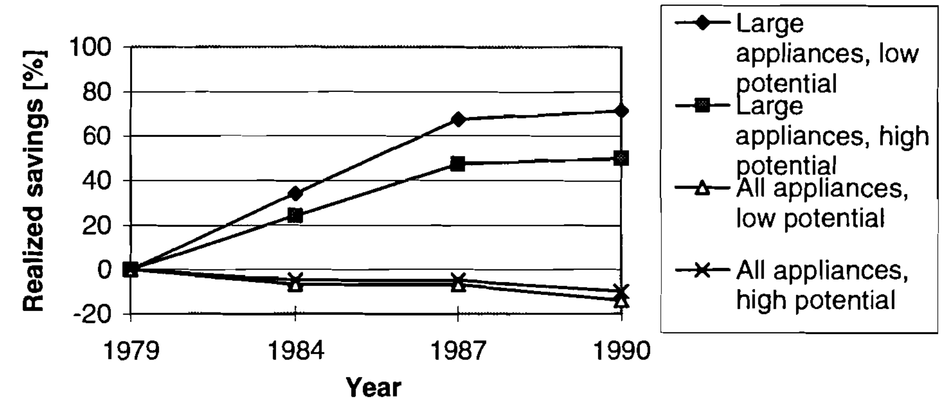

Figure 5.3 Realized savings in percentage of estimated potential for energy conservation in electrical appliances, for high and low estimates of potential.

The realized savings for large appliances occur even though the total number of large appliances is increasing. In addition, they occur even though electricity prices were decreasing most of the time. For the total sector this development is neutralized by increasing demand from new types of appliances (not identified). This is a clear example of a case where the dynamic nature of energy demand cannot be captured by the more static estimates of conservation potential.

Electrical appliances disaggregated

When each of the large appliances is considered separately the growth pattern varies considerably for different end uses. One can also distinguish between two different types of appliances within the group of large appliances, namely "stagnant" and "growing" appliances. The "stagnant" appliances already had a high level of market penetration by 1979. The final energy demand decrease as they approach saturation and are gradually exchanged for more efficient models (Figure 5.4). For the "growing" appliances, on the other hand, the market penetration levels were low in 1979 and have been increasing markedly since, resulting in increasing FED (Figure 5.5).

Stoves, ovens, refrigerators, and freezers are examples of "stagnant" appliances; clothes dryers and dishwashers are examples of "growing" appliances. Interestingly, the demand for lighting, which was one of the very first end uses for electricity is still increasing. Also, the energy demand for clothes dryers started decreasing in 1987, indicating a saturation of this specific end use.

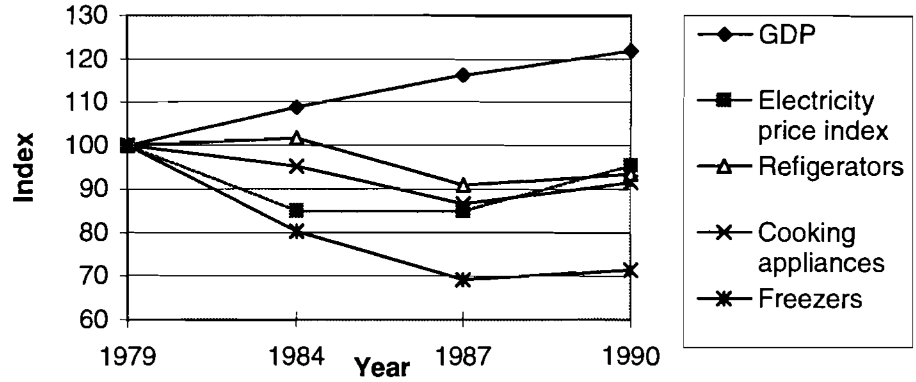

Figure 5.4 Relative development of energy demand compared with development of GDP for some large appliances with low demand growth.

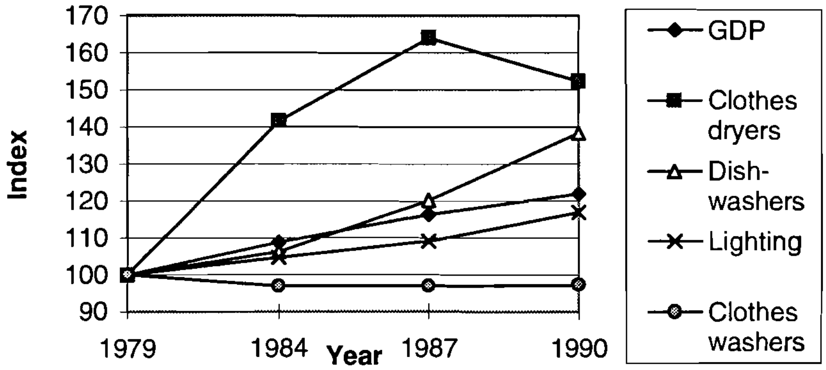

Figure 5.5 Relative development of energy demand compared with development of GDP for some large appliances with high demand growth.

The realized savings for the different end uses ranges from -29% (dishwashers) of the estimated potential to 77% (freezers, conservative potential) of the estimated potential. In Table 5.2 the realized savings are presented as a percentage of the estimated potential. The estimated potential used for this table is based on calculation method two; i.e., the energy reduction for each measure is calculated in percentage of the Swedish "normal" energy use in 1979. For clothes dryers no realized savings are presented because clothes dryers do not have any costefficient estimated conservation potential for 1979. The growth rate of energy demand for clothes dryers was still lower than the growth rate of GDP.

Realized savings (%)	**1979**	**1984**	**1987**	**1990**
Cooking appliances	0	32	69	71
Refrigerators	0	11	40	45
Freezers	0	43	71	77
Clothes washers	0	18	30	38
Dishwashers	0	5	-7	-29
Lighting	0	14	24	17

Table 5.2 Realized savings in percentage of estimated potential, based on calculation method two.

Demand decoupling factors

The CDDFs for electrical appliances can be calculated analogously to the calculation for the building sectors (Table 5.3).

CDDF (%/year)	**Average**
Electrical appliances in households, FED	
All appliances	-0.36
Large appliances, total	2.36
Cooking appliances	2.64
Refrigerators	2.44
Freezers	4.84
Clothes washers	2.08
Dishwashers	-1.16
Clothes dryers	-2.07
Lighting	0.39

Table 5.3 Approximate values of the DDFs (related to FED) for electrical appliances between 1979 and 1990.

The aggregated DDF for the larger appliances that were available in 1979 is large; however, the DDF for *all* the electricity used in the residential sector for purposes other than heating is negative. This is a clear example of the dynamic changes of energy demand sectors that are usually not taken into account by engineering studies of the conservation potential.

6. Personal Transportation Sector

This study of the personal transportation sector has been limited to the conservation potential and development of energy demand for cars. The estimate of the conservation potential is based on an English study (Olivier and Miall, 1983), and the statistics on energy demand development are taken from Schipper et al. (1993).

6.1 Cars

Conservation supply curve

No study of the potential for technological efficiency improvements in Swedish cars in 1979 has been found in the literature. The most extensive study for a reasonably similar situation (for a European country in the late seventies) that has been found, considers cars for the UK in 1976 (Olivier and Miall 1983). The averages of energy consumption per car in 1976 in the UK (46 GJ/yr) and in Sweden (47.3 GJ/yr) coincide well, which indicates a comparable starting point. To achieve a common reference year for the different sectors, the conservation potential should relate to the year 1979. In that year the average energy consumption per car had risen to 49.1 GJ/yr. Because no large improvements in energy efficiency of the cars occurred between 1976 and 1979, the data for 1976 have been used directly.

In Olivier and Miall (1983) the costs per GJ (annualized with a 5% discount rate) are given in 1977 British pounds for a number of different conservation measures in cars. Only those measures concerning new cars are considered in this study. Also, only those measures expected to be available during the 1980s are taken into account. The costs are converted to 1980 SKr/MWh and the total savings possible from each measure are calculated as the savings per car times the car stock in Sweden in 1979. With this information a CSC for the Swedish car stock in 1979 is constructed.

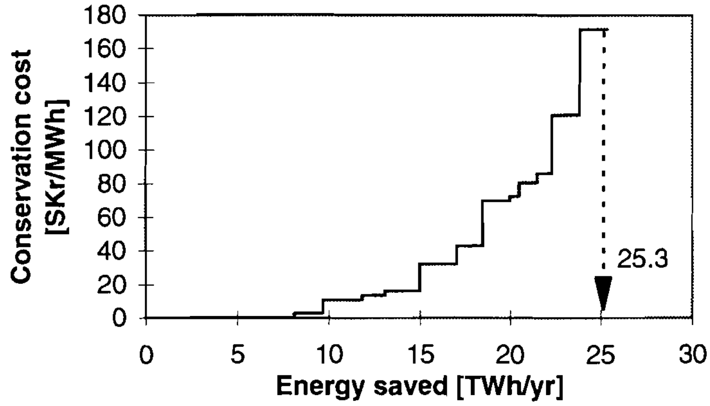

Figure 6.1 Conservation supply curve for the car stock for 1979 in Sweden. The total potential of 25.3 TWh/yr, or 65% of total FED for cars in 1979, is cost efficient (compared with the gasoline price in 1979).

Final energy demand

The development of energy demand is available in official statistics. In this study it is taken from Schipper et al. (1993). The information is available both in final energy (gasoline/diesel oil used) and in passenger kilometers.

Gasoline prices

The price development for energy for cars, i.e. gasoline and diesel oil, is directly available in official Swedish statistics (SCB 1982/83, 1986, and 1992).

6.2 Analysis and Results

The data in Olivier and Miall (1983) seem to present an optimistic scenario concerning both energy-conservation potentials and costs of conservation measures. With the derived CSC, *all* the specified efficiency measures would be cost efficient to apply (Figure 6.1). This results in a savings potential of over 25 TWh/yr, or 65% of the total energy used by cars in Sweden in 1979.

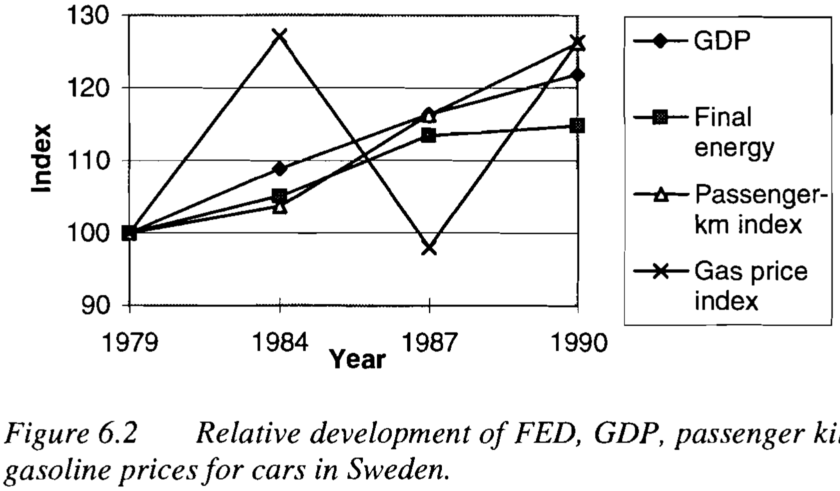

Figure 6.2 Relative development of FED, GDP, passenger kilometers, and gasoline prices for cars in Sweden.

The FED for cars grows somewhat slower than does GDP (Figure 6.2). Initially, the total number of passenger kilometers also grows more slowly than GDP, but after 1984 the growth rate is considerably faster. The price sensitivity seems weak, but a slower growth at increasing prices and an even faster growth at decreasing fuel prices can be distinguished.

The level of realized savings is low, peaking at 11% of the estimated potential in 1990, which is equivalent to 7% of the sector's FED in 1979 (Figure 6.3).

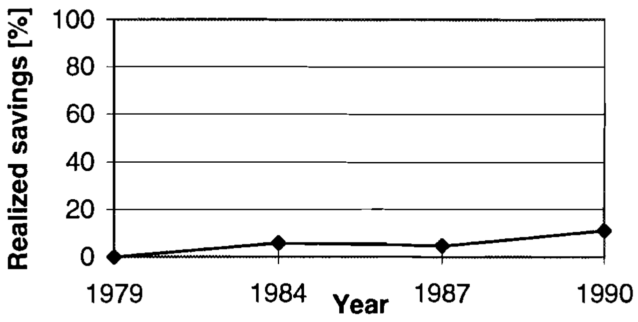

Figure 6.3 Realized savings in the personal transportation sector (cars) in percentage of estimated conservation potential.

One explanation of the low realized savings is the high estimate of conservation potential. Other, more important, factors are the increasing demand for transportation and traveling, the lower "load factor" (fewer passengers per car on average) and a trend toward larger and more powerful cars (Grübler, 1993). These factors all counteract the higher technical efficiency of each vehicle. The energy efficiency of the car is only one of several factors that influence the consumer's choice.

The CDDF for gasoline for cars between 1979 and 1990 was 0.57.

7. Summary and Conclusions

In this study three different sectors have been examined: space and water heat for the building sector, electric appliances in homes, and cars. The total number of sectors studied is larger, because the two first main sectors have been divided into as many subsectors as the available statistics allow. The most reliable and extensive information found has been regarding heat for the residential buildings sector, therefore the analysis of this sector is especially extensive. The time frame studied is from 1979 to 1990.

Two types of diagrams have been constructed for each sector and for each subsector: one illustrates the development of energy demand related to the growth of the GDP and other factors, and one illustrates the realization over time of energy savings in relation to the estimated conservation potential. The latter illustrates the core of this study, namely the transformation from a static conservation potential to the dynamic development of actual energy demand. From the first type of diagram values of the energy DDFs (see Section 2.4) have been derived for the various sectors.

The purpose of the study is to examine the relationship between the potential for energy conservation in some demand sectors and the actual development of energy demand in these sectors. A hypothesis was that the importance of the technical economic potential for energy conservation differed between different types of sectors. Other factors influencing the development of energy demand are future technological development and other dynamic structural and behavioral changes in the sectors.

Below are some conclusions formulated for each main sector and some observations regarding the complete comparative study made.

Space and water heating in buildings

This sector can be regarded as the most static of the sectors studied. More recent revisions of the CSC from 1979 have led only to minor changes, apart from savings already realized.

In the beginning of the 1980s the Swedish authorities introduced a massive weatherizing program for residential buildings. The realized savings (60% in 1987) derived in this study can be a measure of the success of this program.

The realized savings accumulate over time, but reach their highest level in 1987. Thereafter they decline until the year 1990; this can be explained by behavioral factors. The energy prices slumped in 1986 and stayed low in the following years, leading to decreased interest in energy savings.

Electrical appliances for the residential sector

The use of electricity in homes for purposes other than heating is a dynamic end-use sector that changes continually as new types of electrical appliances (microwave ovens, waterbeds, etc.) are developed and gain a market. The total demand for electricity for domestic appliances in Sweden increased more quickly than did GDP during the time period studied.

For large electrical appliances the electricity demand *decreased* in absolute numbers. Large electrical appliances include appliances that were already known and used in 1979 and whose the number has since been growing slowly due to saturation. The improved efficiency of new appliances of the same type can therefore be seen directly in the aggregate energy use.

This difference between total demand and demand for large electrical appliances is obvious when the CDDFs (see Table 6.1) are compared. This sector is thus a clear example of a case where the dynamic nature of energy demand cannot be captured by the more static estimates of conservation potential.

Personal transportation sector

The personal transportation sector (cars) can also be viewed as being a highly dynamic sector. In this narrow sector it is not new types of vehicles that are developed, but new and extended *uses* of cars. The demand for gasoline for cars increased substantially during the time period studied, but not quite as fast as did GDP (see Figure 6.2).

With a high estimate of the conservation potential, this translates into realized savings of only 11% of the conservation potential.

Comparative analysis

When the development of energy demand for the different sectors is compared, it is obvious that the patterns of growth, as well as of the realization of estimated conservation potentials, differ substantially.

One measure relating the development of energy use to the economic development is the DDF. The observed, historical (compounded) DDFs have been calculated for the various sectors (Table 7.1).

CDDF (%/year)	Average
Heat, residential buildings	
Total Useful Energy Demand	0.72
Total Final Energy Demand	2.05
Heat, commercial buildings, total useful energy demand	0.94
Electrical appliances in households (final energy demand)	
All appliances	-0.36
Large appliances	2.36
Transportation (cars)	0.57

Table 7.1 Values of the CDDFs for different sectors in Sweden between 1979 and 1990.

There are two important conclusions that can be drawn from these calculations; *first*, it is very important to understand the energy system and to know if the DDF used refers to primary, final, or useful energy; and *second*, the size of the DDF is determined by on the level and method of disaggregation into different end use sectors. Both conclusions indicate the importance of an analysis based on the reference energy system (see Figure 2.2).

It is also obvious that, when used on a sectoral basis, the DDFs are often well above one or below zero. This is an important detail when compared with the average values (between zero and one) used for aggregate studies of the energy system (Manne and Richels, 1992).

In Figure 7.1, the realized savings for several of the sectors and subsectors studied can be compared directly.

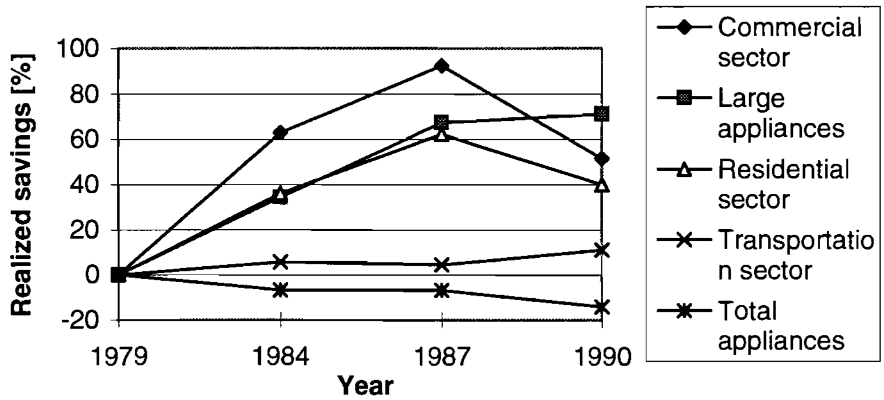

Figure 7.1 Realized savings for several of the sectors and subsectors studied.

From this graph one can conclude that the CSCs (or cost-efficient technical energy conservation potential) have a greater influence on the development of energy demand for buildings and for the already established large electrical appliances than for total electricity demand for domestic appliances and for cars. This is to say that conservation potentials as such are not sufficient to predict energy demand. Other factors, such as consumer preference, must be considered when theoretical savings potential is assessed.

Final remarks

In this type of study there are inherent uncertainties related to with the statistical material over energy demand and the estimates of energy-conservation potential used. There is a high uncertainty in the division of electricity use between different end uses within a building and the calculation of UED (for space and water heating) depending on estimated conversion efficiencies. Since it is mainly the incremental changes in energy use that are studied, the analysis is sensitive to this kind of uncertainties. One should also note the sensitivity of the resulting realized savings on the choice of conservation potential.

Nevertheless, we have some confidence in the presented results. Both the treatment of statistical material and the choice of energy-conservation studies have been made with the goal to be as *consistent* as possible in order to make the *comparisons* over time and between the sectors reliable.

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Appendix A

Building stock in Sweden in 1979

One of the main inputs to the calculation program HOVA is information about the building stock in the year for which the conservation potential is to be calculated. The building stock is divided into four different age classes, those built before 1950, from 1951 to 1965, from 1966 to 1975, and from 1976 to 1979. The different classes have different data on conservation measures and energy use. All the data are also given for SFHs and MFHs separately.

Information about the building stock is taken from the publications of the National Central Bureau of Statistics from as near to 1979 as possible. The data on the building stock for the first three periods come from "Energy Statistics for One- or Two-Dwelling Houses in 1980" (SCB 1981a) and "Energy Statistics for Multi-Dwelling Houses in 1980" (SCB 1981b). For the last period the 1982 versions of the same publications were used (SCB 1982a and 1982b). In Table A.1 below, "Electricity" contains data for houses using only electricity together with 80% of the houses using both electricity and fuel wood (Schipper et al., 1993). "Fuels" includes all houses using oil (together with other fuels), the houses using only fuel wood, 20% of the houses using both electricity and fuel wood, and the houses labeled "Övrigt" (others) in the statistics. Finally, the "District heating" group consists of houses heated with district heating and "kvarterscentraler" (block centrals).

Year of construction/ Fuels used	**Prior to 1950**	**1951-1965**	**1966-1975**	**1976-1979**
Electricity	163.0	45.1	142.5	105.4
Fuels	526.6	217.6	146.8	21.1
District heating	6.6	23.0	36.0	18.9
Total	**696.2**	**285.7**	**325.3**	**145.4**

Table A.1 Building stock for SFHs in thousands of dwellings, used for construction of CSC.

Year of construction/ Fuels used	**Prior to 1950**	**1951-1965**	**1966-1975**	**1976-1979**
Electricity	642	32	1,711	998
Fuels	17,775	21,607	14,719	866
District heating	12,460	18,440	25,492	3,106
Total	**30,877**	**40,079**	**41,994**	**4,970**

Table A.2 Building stock for MFHs in thousands of square meters, used for construction of CSC.

For commercial buildings the data on the building stock in 1979 are taken from "Energy Statistics for Buildings with Premises in 1980" (SCB 1981c) for the periods up to 1975. For the period from 1976 to 1979 the corresponding publication from 1982 is used (SCB 1982c).

Year of construction/ Fuels used	**Prior to 1950**	**1951-1965**	**1966-1975**	**1976-1979**
Electricity	1,375	949	1,681	2,420
Fuels	27,282	11,018	12,113	12,314
DH	13,668	10,462	13,813	13,375
Total	**42,325**	**22,429**	**27,607**	**28,109**

Table A.3 Commercial building stock in thousands of square meters, used for construction of CSC.

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Appendix B

Data charts for space and water heating in buildings

The data are divided into four subsectors, the last one having two alternatives:

- Residential buildings (total),
- Single family houses,
- Multifamily houses,
- Commercial buildings
    1. "main case" with data based on statistics presented in Schipper et al. (1993), this is the case presented in this report,
    2. "alternative case" with data based directly on SCB statistics (SCB 1989 and 1993).

Note: In the appendix comma is used as a decimal marker.

APPENDIX B

TOTAL RESIDENTIAL SECTOR

	1979	1984	1987	1990
Conservation potential [TWh/yr]	14,3	14,3	13,0	14,3

Useful energy, space and water heat in residential sector [TWh]

	1979	1984	1987	1990
Liguid fuels	35,2	20,3	17,7	19,2
Solid fuels	4,1	7,2	6	8,2
Electricity	11,4	20	22,3	23,6
District heating	12,4	16	18,5	20,2
Total	**63,1**	**63,5**	**64,5**	**71,2**
Relative	100,0	100,6	102,2	112,8
UED if growth as GDP	63,1	68,7	73,4	76,9

Final energy, space and water heat in residential sector [TWh]

	1979	1984	1987	1990
Liquid fuels	55,9	30,7	24,9	26
Solid fuels	7,4	13,1	10,8	14,9
Electricity	11,8	20,6	23	24,3
District heating	13,1	16,8	19,5	20,8
Total	**88,2**	**81,2**	**78,2**	**86**

GDP in billions of '80 US$ and population in millions

	1979	1984	1987	1990
GDP	74,1	80,6	86,2	90,3
Population	8,29	8,34	8,40	8,56

Indexed development of UED and other factors

	1979	1984	1987	1990
GDP	100	108,8	116,3	121,9
Useful energy demand	100	100,6	102,2	112,8
Population	100	100,6	101,3	103,3
Heat price	100	112,4	80,3	89,3

Difference between actual demand and demand following GDP growth

	1979	1984	1987	1990
Realized savings (%)	0,0	36,1	68,4	40,1
Realized savings (TWh)	0	5,2	8,9	5,7

SINGLE FAMILY HOUSES

	1979	1984	1987	1990
Conservation potential [TWh/yr]	7,7	7,7	7,4	7,7

Useful energy, space and water heat [TWh], climate corrected

	1978	1979	1984	1987	1990
Oil	19,6		9,9	9,7	11,8
Solid fuels	3,2		6,4	5,6	6,5
DH	1,2		1,7	1,7	2,2
Electricity	8,7		17,4	18,4	19,9
Total	**32,7**	**33,0**	**35,4**	**35,5**	**40,4**
Relative		100,0	107,4	107,6	122,5
UED if growth as GDP		33,0	35,9	38,3	40,2

Final energy demand [TWh], directly from statistics

	1978	1979	1984	1987	1990
Oil	33,9		14,8	15,9	15,0
Solid fuels	6,0		11,0	11,0	10,2
District heating	1,4		1,8	2,1	2,1
Electricity	9,3		16,9	20,5	17,8
Total	**50,6**		**44,5**	**49,5**	**45,1**

GDP in billions of '80 US$ and population in millions

	1979	1984	1987	1990
GDP	74,1	80,6	86,2	90,3
Pop.	8,29	8,34	8,40	8,56

Relative development of GDP, useful energy demand, population and heat prices.

	1979	1984	1987	1990
GDP	100	108,8	116,3	121,9
Useful energy demand	100	107,4	107,6	122,5
Population	100	100,6	101,3	103,3
Heat price	100	98,8	79,6	92,9

Difference between actual demand and demand following GDP growth

	1979	1984	1987	1990
Realized savings (%)	0,00	6,0	38,7	-2,6
Realized savings (TWh)	0	0,5	2,9	-0,2

MULTI FAMILY HOUSES						APPENDIX B	
	1979	1984	1987	1990			
Conservation potential	6,5	6,5	5,6	6,4			
[TWh/yr]							
Useful energy, space and water heat [TWh], climate corrected							
	1978	1979	1984	1987	1990		
Oil	16,4		10,2	7,7	6,0		
Solid fuels	0,1		0,2	0,2	0,1		
District heating	12,8		16,5	19,1	19,2		
Electricity	0,6		1,5	2,1	2,1		
Total	**29,9**	**30,1**	**28,5**	**29,1**	**27,4**		
Relative		100,0	94,6	96,4	90,8		
UED if growth		30,1	32,8	35,1	36,7		
as GDP							
Final energy demand [TWh], directly from statistics							
	1978	1979	1984	1987	1990		
Oil	24,3		13,2	11	6,7		
Solid fuels	0,2		0,4	0,3	0,1		
District heating	14		16,4	21,7	17		
Electricity	0,6		1,5	2,3	1,9		
Total	**39,1**		**31,5**	**35,3**	**25,7**		
GDP in billions of '80 US$ and population in millions							
	1979	1984	1987	1990			
GDP	74,1	80,6	86,2	90,3			
Population	8,29	8,34	8,40	8,56			
Relative development of GDP, useful energy demand,							
population and heat prices.							
	1979	1984	1987	1990			
GDP	100	108,8	116,3	121,9			
Useful energy demand	100	94,6	96,4	90,8			
Heat price	100	103,5	85,6	94,4			
Population	100	100,6	100,7	103,3			
Difference between actual demand and demand following GDP growth							
	1979	1984	1987	1990			
Realized savings (%)	0,00	65,3	107,2	147,2			
Realized savings (TWh)	0	4,3	6,0	9,4			

MULTI FAMILY HOUSES						APPENDIX B	
COMMERCIAL BUILDINGS, main case							
	1979	1984	1987	1990			
Potential	6,2	6,2	6,1	6,2			
[TWh/yr]							
Useful energy demand, space and water heat [TWh], climate corrected							
	1978	**1979**	**1984**	**1987**	**1990**		
Liquid fuels	14,5	15,9	10,6	8,6	9,0		
Solid fuels	0,1	0,1	0,1	0,1	0,1		
District heating	8,7	8,9	11,4	12,6	13,8		
Electricity	1,9	2,0	3,3	4,3	6,7		
Total	**25,1**	**26,9**	**25,4**	**25,6**	**29,6**		
Relative		100,0	94,4	95,2	110,1		
UED if growth							
as GDP		26,9	29,3	31,3	32,8		
Final energy demand [TWh], directly from statistics							
	1978	**1979**	**1984**	**1987**	**1990**		
Oil	25,2	24,0	13,7	12,3	10,0		
Solid fuels	0,1	0,2	0,2	0,2	0,2		
District heating	9,5	9,9	11,1	14,3	12,2		
Electricity	2,0	2,2	3,2	4,8	6,7		
Total	**36,8**	**36,3**	**28,2**	**31,6**	**29,1**		
GDP in billions of '80 US$ and commercial floor area in 10e6 m2							
	1979	**1984**	**1987**	**1990**			
GDP	74,1	80,6	86,2	90,3			
Floor area	143	158	167	177			
Relative development of GDP, useful energy demand, heat prices and floor area							
	1979	**1984**	**1987**	**1990**			
GDP	100	108,8	116,3	121,9			
Useful energy demand	100	94,4	95,2	110,1			
Heat price	100	103,5	85,6	94,4			
Floor area	100	110,5	116,8	123,8			
Difference betwee actual demand and demand folloing GDP growth							
	1979	**1984**	**1987**	**1990**			
Realized savings (%)	0	63,0	94,0	51,6			
Realized savings (TWh)	0	3,9	5,7	3,2			

MULTI FAMILY HOUSES						APPENDIX B
COMMERCIAL BUILDINGS, Alternative case						
	1979	1984	1987	1990		
Conservation potential	6,2	6,2	6,1	6,2		
[TWh/yr]						

Useful energy demand, space and water heat [TWh], climate corrected					
	1978	1979	1984	1987	1990
Liquid fuels	15,7		9,7	8,0	8,5
Solid fuels	0,1		0,1	0,1	0,1
District heating	7,2		9,3	10,2	12,9
Electricity	1,9		3,3	4,3	6,7
Total	**24,8**	**26,6**	**22,4**	**22,6**	**28,2**
Relative		100,0	84,1	84,9	106,1
UED if growth					
as GDP		26,6	28,9	30,9	32,4

Final energy demand [TWh], directly from statistics					
	1978	1979	1984	1987	1990
Oil	23,3		12,5	11,2	9,2
Solid fuels	0,2		0,2	0,2	0,2
District heating	7,8		9,2	11,6	11,4
Electricity	2,0		3,2	4,8	6,0
Total	**33,3**		**25,1**	**27,8**	**26,8**

GDP in billions of '80 US$ and commercial floor area in 10e6 m2				
	1979	1984	1987	1990
GDP	74,1	80,6	86,2	90,3
Floor area	143	158	167	177

Relative development of GDP, UED, heat prices and floor area				
	1979	1984	1987	1990
GDP	100,0	108,8	116,3	121,9
Useful energy demand	100,0	84,1	84,9	106,1
Heat price	100,0	103,5	85,6	94,4
Floor area	100,0	110,5	116,8	123,8

Difference between actual demand and demand following GDP growth				
	1979	1984	1987	1990
Realized savings (%)	0	106,7	137,9	68,2
Realized savings (TWh)	0	6,6	8,3	4,2

Appendix C

Data charts for electrical appliances in the residential sector

The data are presented for both electrical appliances for the residential sector in aggregated form and for each large appliance type separately.

The conservation potentials for the various appliances are calculated according to two different methods; method one, or "savings if in absolute numbers" and method two, or "savings if in percent."

Note: In the appendix comma is used as a decimal marker.

APPENDIX C

ELECTRIC APPLIANCES in the RESIDENTIAL SECTOR

Data on the large appliances studied

	Average Swedish unit consumption 1979	Market penetration in Sweden 1979	Total number of appliances in Sweden 1979	Average Danish unit consump. 1975	Cost for conserv. measures
	[kWh/yr]	[%]	[10e6]	[kWh/yr]	1975$
Electric stove	660	100	3,46	950	60
Refrigerator	559	103	3,56	550	20
Freezer	1166	76	2,63	800	38
Washing machine	413	73	2,53	575	27
Clothes dryer	281	22	0,76	625	115
Dishwasher	298	27	0,93	650	30
Lighting	631	100	3,46	115	0

Savings if in absolute numbers

	Unit consumption after measures	Savings per Swedish unit	Total savings after measures	Cost of saved energy	Cost-eff. potential
	[kWh/yr]	[kWh/yr]	[GWh/yr]	[79SEK/MWh]	[GWh/yr]
Electric stove	540	120	415	411	0
Refrigerator	200	359	1279	46	1279
Freezer	270	896	2356	35	2356
Washing machine	200	213	539	104	539
Clothes dryer	260	21	16	4499	0
Dishwasher	285	13	12	1896	0
Lighting	504	127	439	0	439

Savings if in percentage

	Savings in % of Danish unit cons.	Savings per Swedish unit	Total savings after measures	Cost of saved energy	Cost-eff. potential
	[%]	[kWh/yr]	[GWh/yr]	[79SEK/MWh]	[GWh/yr]
Electric cooker	43	284	982	174	982
Refrigerator	64	358	1275	46	1275
Freezer	66	770	2024	41	2024
Washing machine	65	268	679	83	679
Clothes dryer	58	163	124	580	0
Dishwasher	56	167	156	148	156
Lighting	30	189	655	0	655

Optimistic conservation potential, for all years:	6,1	TWh/yr
Conservative conservation potential, for all years:	4,3	TWh/yr

ELECTRIC APPLIANCES, AGGREGATED

Development of final energy demand [TWh], GDP [10e9 80US$], and electricity price [SKr/MWh]

	1979	1984	1987	1990
GDP	74,1	80,6	86,2	90,3
Final energy dem.	12,38	13,76	14,69	15,69
FED if growth as GDP	12,38	13,47	14,40	15,09
FED for large appliances only	11,05	10,55	9,95	10,41
FED for large appliances if growth as GDP	11,05	12,02	12,85	13,47
Electricity price	260	360	420	585

Difference between actual demand and demand following GDP;
realized savings of optimistic and conservative potential

	1979	1984	1987	1990
FED (TWh)	0,0	-0,3	-0,3	-0,6
In % of potential				
Optimistic pot.	0,0	-4,8	-4,8	-9,8
Conservative pot.	0,0	-6,7	-6,7	-14,0
FED (TWh) for large appliances	0,0	1,5	2,9	3,1
In % of potential				
Optimistic pot.	0,0	24,1	47,5	50,2
Conservative pot.	0,0	34,2	67,4	71,2

ELECTRIC APPLIANCES, DISAGGREGATED

Actual development of final energy demand [GWh/yr]

	1979	1984	1987	1990
Cooking appliance	2278	2167	1972	2083
Refrigerators & Co	1992	2024	1810	1860
Freezers	3066	2463	2121	2188
Washing machine	1043	1011	1011	1013
Clothes dryers	214	303	351	326
Dishwashers	278	296	335	385
Lighting	2183	2286	2383	2553
Other appl.	1323	3208	4706	5284

Development of final energy demand IF the same growth rate as GDP [GWh/yr]

	1979	1984	1987	1990
Cooking appl.	2278	2478	2649	2777
Refrigerators & Co	1992	2167	2317	2428
Freezers	3066	3336	3566	3738
Washing machines	1043	1135	1213	1272
Clothes dryers	214	233	249	261
Dishwashers	278	303	324	339
Lighting	2183	2375	2539	2661
Other appl.	1323	1440	1539	1613

APPENDIX C

Realized savings in GWh/yr

	1979	1984	1987	1990
Cooking appl.	0	311	677	694
Refrigerators & Co	0	144	507	568
Freezers	0	872	1445	1550
Washing machines	0	124	202	258
Clothes dryers	0	-70	-102	-65
Dishwashers	0	7	-11	-45
Lighting	0	89	156	108

Realized savings in percent of conservation potential calculated with absolute values (method one)

	1979	1984	1987	1990
Cooking appl.	0	-	-	-
Refrigerators & Co	0	11	40	44
Freezers	0	37	61	66
Washing machines	0	23	38	48
Clothes dryers	0	-	-	-
Dishwashers	0	-	-	-
Lighting	0	20	35	25

Realized savings in percent of conservation potential calculated in percent (method two)

	1979	1984	1987	1990
Cooking appl.	0	32	69	71
Refrigerators & Co	0	11	40	45
Freezers	0	43	71	77
Washing machines	0	18	30	38
Clothes dryers	0	-	-	-
Dishwashers	0	5	-7	-29
Lighting	0	14	24	17

Indexed development of final energy demand for the various large appliances, and for the remainder of total electricity demand for appliances; small appliances

	1979	1984	1987	1990
GDP	100,0	108,8	116,3	121,9
El price index	100,0	85,0	85,0	95,3
Cooking appl.	100	95,1	86,6	91,4
Refrigerators & Co	100	101,6	90,9	93,4
Freezers	100	80,3	69,2	71,4
Washing machines	100	96,9	96,9	97,2
Clothes dryers	100	141,6	164,0	152,2
Dishwashers	100	106,2	120,2	138,2
Lighting	100	104,7	109,2	116,9
Other, small appliances	100	242,4	355,6	399,3

Appendix D

Data charts for the personal transportation sector (cars)

Data on conservation potential are adapted from Olivier and Miall (1983).

Note: In the appendix comma is used as a decimal marker.

				APPENDIX D	
PERSONAL TRANSPORTATION SECTOR					
Conservation measures for new cars (after 1976)					
	Cost for measure	**Energy sav. per car**	**Energy sav. per car**	**Cost for saved energy**	**Total sav. in Sweden**
	['81£/GJ]	**[GJ]**	**[%]**	**['80SEK/MWh]**	**[TWh/yr]**
Improved structural des.	neg	7,2	15,2	neg	5,71
Near-term weight red.	-	3,0	6,3	-	2,38
Red. aerodynamic drag	0,1	2,0	4,2	2,7	1,59
Valve resizing	0,4	2,7	5,7	10,7	2,14
El. engine controls	0,5	1,6	3,4	13,4	1,27
Low-fr. engine coatings	0,6	2,4	5,1	16,1	1,90
Autom. on-off controls	1,2	2,6	5,5	32,2	2,06
Near-term impr. tyres	1,6	1,8	3,8	42,9	1,43
Direct-injection turbo	2,6	1,9	4,0	69,8	1,51
Indirect-inj. turbo diesel	2,7	0,6	1,3	72,5	0,48
Constant speed acc.	3,0	1,3	2,7	80,5	1,03
Improved lubricants	3,2	1,0	2,1	85,9	0,79
Cont.-variable trans.	4,5	1,9	4,0	120,8	1,51
Hybr. drive&energy stor.	6,4	1,9	4,0	171,7	1,51
TOTAL		**31,9**			**25,31**
Conservation potential 1979		25,31	TWh/yr		
Development of GDP, final energy demand, gasoline price and passenger kilometers					
	1979	**1984**	**1987**	**1990**	
GDP [10e9 ´80 US$]	74,1	80,6	86,2	90,3	
Final energy [TWh/yr]	38,97	40,94	44,19	44,69	
FED if growth as GDP	38,97	42,40	45,32	47,50	
Gasoline price (´80SEK/l)	2,47	3,14	2,42	3,12	
Passenger km (10e9)	68,5	71	79,6	86,4	
Realized savings in absolute numbers and in percent of conservation potential					
	1979	**1984**	**1987**	**1990**	
Realized savings [TWh/yr]	**0**	**1,5**	**1,1**	**2,8**	
Realized savings [%]	0	5,8	4,5	11,1	